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The areas of research cover a diverse spectrum from deterministic and stochastic differential games through identification and filtering all the way to system synthesis. For further information on details refer to the final report.

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DYNAMICS SYSTEMS CONTROL THEORY

AFOSR-TR- 77-1282

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FINAL REPORT

for

AFOSR Grant 76-2958

December 1, 1976 - August 31, 1977

Principal Investigator:

C. T. Leondes, Professor
The University of California
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FINAL REPORT FOR AFOSR GRANT

UCLA/AFOSR Grant 76 - 2958

Principal Investigators

Professor C. T. Leondes

December 1, 1976 - August 31, 1977

I. INTRODUCTION

This final report is composed of several sections. In the first section past basic research results on earlier year grants are summarized. Then the results of this past year's grant are presented in the next section. Then the concluding section presents a summary and future basic research plans.

II. PAST RESULTS

Over prior years this AFOSR/UCLA program in basic research has been most substantively productive. Close to 200 papers presenting basic research results on a wide range of significant areas have been published in first-rate archival journals. Additionally, over 50 rather [illegible]ive technical reports have been published. In addition to this, sever[illegible] dozen papers have been presented at, and published in, conference proceedings. Also quite a few contributions have been published in the rather highly regarded international annual series, Advances in Control and Dynamic Systems, published by Academic Press. Thus something close to 300 published items have been produced up until now in this AFOSR/UCLA basic research grant activity.

The quality and significance of the wide range of productivity of basic research results in prior years on this grant activity is amply testified to, of course, by the fact that something like 200 papers have been

accepted by, and published in, first-rate archival journals. Additionally, by now the published papers in the wide variety of areas produced on this grant activity are rather widely referenced in the published literature; and this, of course, provides a strong testimony as to the quality and significance of the research results produced in earlier years on this grant activity. Finally, most strong testimony as to the significance of the research results produced this far on this research grant activity is provided by the fact that two major papers prize awards have been granted for papers published under this grant activity. These major paper awards include the Baker Prize Award received in 1970 for publications in 1969, and the Barry Carlton Honorable Mention Award received in 1973 for publications in 1972. Details on these paper prize awards are presented next followed by a listing of some of the research areas of earlier results, and then some brief comments on students who have worked on earlier AFOSR/UCLA research grants.

A. Prize Paper Awards

1. The Baker Prize Award

The IEEE, Institute of Electrical and Electronic Engineers, is the world's largest professional society. It publishes about 33 transactions in such areas as controls, computers, communications, solid state devices, antennas and electromagnetic theory, microwave techniques, nuclear engineering, bio-engineering, and others. Basic research results constituting major advances in such areas as radar, computers, electronics, etc., have appeared in these transactions over the past decades. Each year a paper is selected to receive the Baker Prize Award as the single best

publication in all 33 transactions. This is clearly most significant representation of basic research contributions of substantial prominence. In 1970, this AFOSR/UCLA research grant received this award for the following trilogy of papers published in 1969.

(a) "Constraint Theory, Part I: Fundamentals," G. J. Friedman and C. T. Leondes, Transactions on Systems Science and Cybernetics, SSC: No. 1, January 1969.

(b) "Constraint Theory, Part II: Models Graphs and Regular Relations," G. J. Freidman and C. T. Leondes, Transactions on Systems Science and Cybernetics, SSC: No. 2, April 1969.

(c) "Constraint Theory, Part III: Inequality and Discrete Relations," G. J. Friedman and C. T. Leondes, Transactions on Systems Science and Cybernetics, SSC: No. 3, July 1969.

2. The Barry Carlton Honorable Mention Award

One of the major transactions of the IEEE publishing basic research results is the Transactions on Aerospace and Electronic Systems. Every year an award is given for the best publication of research results in a paper in this Transactions. in 1973 this AFOSR/UCLA grant was the recipient of such an award for the following two companion papers.

(a) "In Flight Alignment and Calibration of Inertial Measurement Units: Part I--General Formulation," J. Baziw and C. T. Leondes, IEEE Transactions on Aerospace and Electronics Systems, AES-8, pp. 439-449, July 1972.

(b) "In Flight Alignment and Calibration of Inertial Measurement Units: Part II--Experimental Results," IEEE Transactions on Aerospace and Electronic Systems, AES-8, pp. 450-465, July 1972.

B. Prior Basic Research Result Areas

This AFOSR/UCLA grant program in basic research had maintained a highly dynamic and diversely prolific research program over the years vigorously pursuing research problems of current significant potential on a continuing basis as the listing below of prior basic research result publication areas should make evident.

1. Deterministic differential games
2. Stochastic differential games
3. Filtering with noise characteristic unknowns
4. System identification (linear and nonlinear)
    (a) Parameter tracking techniques
    (b) Function space techniques
    (c) Digital computer techniques
5. Adaptive system control
    (a) Reference model techniques
    (b) Functional analysis techniques
    (c) Digital computer techniques
6. Final value control systems techniques

7. Singular problems and techniques in linear estimation and control

8. Discrete observers

    (a) Optimal order observers for discrete systems
    (b) Reduced order observers
    (c) Intermediate order observers
    (d) Optimal minimal order observers

9. Continuous observers

10. Extensions in Kalman filter techniques

11. Algorithms for differential games

    (a) Function space methods
    (b) Extensions in quasilinearization
    (c) First order necessary conditions
    (d) Differential dynamic programming with probabilistic criteria functions

12. Algorithms for optimal control

    (a) Extensions in quasilinearization techniques to bounds on control and state
    (b) Methods for control systems with variable criterion functions
    (c) Methods for cost functionals involving convex single valued functions of the state and control variables
    (d) Mayer problem techniques for constrained error coefficient criterion function optimization
    (e) Unrestricted terminal time optimal control techniques
    (f) Methods for optimal control systems with variations in initial conditions.
    (g) The conjugate gradient method with bounds on control and state.
    (h) Two point boundary problem techniques in optimal control synthesis.

13. Neighboring optimal techniques in differential games.

14. Analysis and synthesis of nonlinear systems by Volterra series techniques

    (a) Deterministic systems
    (b) Stochastic systems

15. Constraint theory and systems mathematical model consistency and computational allowability

16. Sensitivity function techniques in systems synthesis

17. Multi-level systems optimization techniques and optimal control synthesis through decomposition

18. Synthesis of distributed paramater systems

    (a) Optimal systems techniques
    (b) Synthesis of suboptimal systems through function space techniques

19. System optimization through functional analysis techniques, minimum normed operators or Krein's L Method.

20. Markov decision processes with state information lag

21. Bayesian decision theory and finite state Markov decision problems

22. Lyapunov function techniques for the stability analysis and synthesis of linear and nonlinear systems

23. The use of entropy techniques for the analysis and synthesis of control systems

24. Nonlinear filtering synthesis

    (a) Stochastic differential equation methods
    (b) Bayesian nonlinear filter techniques
    (c) Methods utilizing the dynamic equations for the evolution of conditional probability density functions

25. Nonlinear smoothing techniques

26. Numerous other research result areas.

C. Research Engineers (Ph.D. Graduate Students) on this AFOSR/UCLA Grant

Over the years this AFOSR/UCLA Grant has produced many top students who have since gone on to key positions of leadership responsibility in the Department of Defense and the aerospace industry. Additionally, this grant has, as a result, fostered an environment through which many outstanding Air Force officers have passed, and who now occupy key positions of responsibility and leadership throughout the Air Force. This, of course, also constitutes a significant facet of this AFOSR/UCLA Grant effort.

III THIS YEAR'S RESULTS

The papers published in archival journals which have been submitted this past year include:

"Parameter Optimization for Linear Quadratic Differential Games," C. T. Leondes and T. K. Siu, Journal of Dynamic Systems, Measurement, and Control, Vol. 99, pp. 58-62, March 1977.

"Least Squares Estimation of Nonstationary Covariance Parameters in Linear Systems," H. W. Brewer and C. T. Leondes, Automatica, Vol. 13, No. 3, pp. 265-277, May 1977.

"An Application of Non-Zero-Sum Games to Competitive Decision Making," Cornelius T. Leondes and Ranjit K. Nandi, International Journal of Systems Science, Vol 8, No. 9, pp 1009-1020, 1977.

"Frequency Domain Interpolation," C. T. Leondes and D. D. Rivers, IEEE Transactions on Aerospace and Electronic Systems, pp. 323-327, May 1977

"Truncation of the Mixed Cauer Form : The Best Approximation in a Definite Mathematical Sense," M. J. Goldman and C. T. Leondes, International Journal of Control, Vol 25, No. 6, pp. 979-982, 1977.

"Asymptotic Properties of the Discrete Minimum Variance Output Feedback Control Law," Albert B. Chammas and Cornelius T. Leondes, Proceedings of the 1977 Joint Automatic Control Conference.

"Minimum Number of Satellites for Three-Dimensional Continuous Worldwide Coverage," Hosam E. Emara and Cornelius T. Leondes, IEEE Transactions on Aerospace and Electronic Systems, Vol. AES-13, No. 2, pp. 108-111, March 1977.

IV OTHER ACTIVITIES THIS PAST YEAR

A. UCLA as a National Center of Excellence and Activity in Control Systems

This past year has seen the continuation of a large and highly active program of graduate education and research in control systems at UCLA. The students continue to take our graduate courses in large numbers, and to pursue graduate degrees at the M.S. and Ph.D. level, also in large numbers. The students, which appear to be as good as any to be found anywhere come from all over the United States and, indeed, from all over the world, being drawn to our program by its international visibility. Certainly, our AFOSR/UCLA Grant program of basic research has played a key role in all this.

B. Editorships of Archival Journals and the Academic Press International Series of Volumes on Control Systems

By now the annual international series published by Academic Press and edited by C. T. Leondes entitled, Advances in Control and Dynamic Systems: Theory and Applications, is one of internationally recognized distinction. Academic Press came to UCLA and to C. T. Leondes for the role of Editor of this series some years ago because of the visibility of our program as a center of excellence on the international scene. This past year Volume 12, whose central theme is advances in filtering theory and stochastic optimal control, was completed and was published in 1976. Additionally, Volume 13, whose central theme

treats advances in applications to complex large scale engineering systems, has been published. Volumes 14, 15, and 16 are in process.

Additionally, the International Journal of Control expanded its advisory board recently to include one member from each of the more active European countries and two from the United States, one from the east coast and one from the west coast. As a result, the International Journal of Control selected C. T. Leondes for membership on its editorial advisory board. In addition to this, C. T. Leondes still retains his capacity as as Associate Editor for the Journal of Optimization Theory and Applications.

C. Presentations at International Meetings

C. T. Leondes served as keynote speaker and additionally as session chairman in December 1974 at an international conference on Optimization in Engineering and Economic Systems, held in Naples. This conference had as chairmen of its sessions internationally prominent individuals from countries in Europe, the United States and the Soviet Union. He has been asked to do this also at an international meeting in Greece in May 1978. Other responsibilities included co-chairing a NATO AGARD (Advisory Group for Aerospace Research and Development) conference and chairing its keynote session. NATO AGARD is composed of internationally prominent figures who are leading technologists from each of the NATO countries. Membership terms are restricted to two terms; however, Professor Leondes has been renewed for an unprecedented sixth term because of his international stature.

C. Air Force Advisory Work

Professor C. T. Leondes continues his active role as an Air Force advisor on most complex and challenging Air Force issues. It is fair to say that Professor Leondes has been called upon to serve as an Air Force advisor because of national prominence achieved as a result of the UCLA program in control systems.

V. SUMMARY

In summary, the AFOSR/UCLA grant program has been a most solidly productive program in basic research in control systems and gives clear indication that it will continue to remain so. According to all evidence it is a national center or excellence and the AFOSR/UCLA grant activity has played a key role in this.